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OPTIMIZATION OF OSMOTIC DEHYDRATION OF POTATO SLICES IN SUGAR SOLUTION USING RESPONSE SURFACE METHODOLOGY

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ABSTRACT

Response surface methodology was used to determine the optimum processing conditions that yield maximum water loss (WL), weight reduction (WR) and minimum solid gain (SG) during osmotic dehydration of potato slices in sugar solution. The experiments were conducted according to Central Composite Design (CCD). The independent process variables for osmotic dehydration process were temperature (20 - 60℃), processing time (80 -300 minutes) and sugar concentration (40 - 60% w/w). For each response, second order polynomial models were developed using multiple linear regression analysis. Analysis of variance (ANOVA) was performed to check the adequacy and accuracy of the fitted models. The response surfaces maps showing the interaction of process variables were constructed. The optimum conditions of dehydration were found to be: temperature 60℃, immersion time 300 min and sugar concentration 40% w/w. At this optimum point, water loss, solid gain and weight reduction were found to be 69,34(g/100 g initial sample), 3,56 (g/100 g initial sample) and 66,8(g/100 g initial sample) respectively. Frying the potato slices previously dehydrated has reduced the frying time to 40.47 %.

KEYWORDS: Optimization, Osmotic Dehydration, Potato Slices, Response Surface Methodology, Sugar Solution

INTRODUCTION

Potato has long been considered as a simple root without taste or flavor. Today it is one of the staples of our diet, but it took centuries for it to be recognized.

In Algeria, production of potato has grown remarkably in recent years. In 2011, it reached 3.8 million tons, against 3.2 million in 2010 and 2.67 million in 2009 (Djouadi F., 2012).

Potato is not only grown for immediate household consumption, but it is more raw material for the food processing industry. Currently, the growth of this industry has increased to meet the growing demand of the fast-food industry, snacks and convenience foods. This growth is mainly due to the increase in the urban population, the diversification of diets and lifestyles that leave less time for preparing the fresh product.

Osmotic dehydration is a process of partial removal of water by soaking foods, mostly fruits and vegetables, in hypertonic solutions. The driving force for the diffusion of water from the plant tissue into the solution is difference between osmotic pressures of the hypertonic solution and plant tissue. The diffusion of water is accompanied by simultaneous counter diffusion of solutes from the solution into the tissue (Lazarides, Katsanidis, Nickolaidis, 1995).

Osmotic dehydration, which is effective even at ambient temperature and protects the colour, flavour and texture of food from heat, is used as a pretreatment to improve the nutritional, sensorial and functional properties of food. The

food, which has been osmotically dehydrated, can be further processed by freezing, freeze-drying, vacuum drying and air drying (Nanjundaswamy and al., 1978). The other major application is to reduce the water activity of food materials so that microbial growth will be inhibited. Since most food materials contain large amount of water, it is cost intensive to ship, pack and store (Biswal and Le Maguer, 1989). The development of new and improved processed products from potato appears to represent an excellent means of increasing the utilization of this high yielding and nutritious species. Potato pretreated by osmotically in sucrose/salt solutions can be used as a quick-cooking product or as an ingredient in salads and soup mixes. Krokida, Oreopoulou, Maroulis, and Marinos-Kouris (2001) reported osmotic dehydration as an effective pretreatment to decrease oil uptake during frying of potatoes.

In this study, it is aimed to investigate the effects of temperature, processing time, sucrose concentration on the mass transfer phenomena during osmotic dehydration of potato slices in sucrose solution, to model water loss, solid gain, weight reduction and to find the optimum operating conditions that maximize water loss and weight reduction and minimize the solid gain.

To our knowledge, little research has been conducted on potato frying dehydrated, and to prove the effectiveness of the process of osmotic dehydration in reducing the cooking time, we carried out a test of frying potato slices.

MATERIALS AND METHODS

Materials

Potatoesspunta variety native to the region of Biskrawere purchased locally and stored at +5°C prior to the experiments. They were thoroughly washed with water to remove soil and other debris. Sugar, the osmotic agent, was purchased from a local supermarket. The osmotic solution is prepared by mixing the sugar with proper amount of pure water.

- **Experimental Procedure**

Potatoes were peeled manually and sliced 0.5 mm thick and 2,2g weight using a slicing machine.

Potato slices undergo bleaching in water at 100°C for 30 seconds then introduced into ice water to stop the effect of bleaching. To prevent non-enzymatic browning reactions, samples are immersed in a 1% sodium metabisulfite solution for 1min, rinsed with distilled water. After these pretreatments, potato slices undergo osmotic dehydration at 20, 40, 60°C in sucrose syrups at 40, 50, 60° Brix. The ratio of product and the desiccant solution is 1: 5. The samples weighed and bleached are immersed in the dehydrating solution, and then placed in a water bath with an agitation speed of 150 turn / min for a duration of 80, 150 and 300 minutes. The device used is a set of agitator and water bath.

For each experiment, the samples were removed from the osmotic solution every 40 minutes, dried with blotting paper and then weighed using a Sartorius balance, then they are returned to the solution until the completion of experience (AOAC, 1980). At the end of the latter, three sampleswere used to determine the water content with infrared moisture meter; the average value was taken for further calculations.

In order to follow adequately the osmotic dehydration kinetics, an individual analysis for each sample was carried out, weight reduction (WR), water loss (WL) and solid gain (SG) data were obtained, according to the expressions proposed by Azuara and al., (1998).

$$WR = \frac{M_0 - M}{M_0} * 100 \quad (1)$$

$$WL = \frac{(M_0 * X_{WO}) - (M * X_W)}{M_0} * 100 \quad (2)$$

$$SG = \frac{(M_0 * X_S) - (M * X_S)}{M_0} * 100 \quad (3)$$

M_0: Initial mass of sample, (g);

M: Mass of sample after dehydration, (g);

X_{W0}: Initial mass of water;

X_W: Mass of water after osmotic dehydration at time (t);

X_{S0}: Initial mass of solids;

X_S: Mass of solids after osmotic dehydration at time (t).

Experimental Design and Statistical Analysis

The response surface methodology (RSM) was used to estimate the main effects of the different factors of the process (temperature, time and sugar concentration) on water loss (WL), weight reduction (WR) and the solid gain (SG) in the osmotic dehydration of the potato slices.

The response surfaces were obtained using the experimental design 8.0.6 Trial software, which allows you to view the combined effects of two factors on the response (temperature, time), (temperature, sugar concentration), (time, sugar concentration), while keeping the third in constant values.

The following second order polynomial model was fitted to the data. Three models of the following form were developed to relate three responses (Y) such as WL, WR and SG to three process variables (x):

$$Y_k = \beta_{k0} + \sum \beta_{ki} x_i + \sum \beta_{kii} x_{ii}^2 + \sum \beta_{kij} x_i x_j$$

(k=1,2,3)

Where β_{k0}, β_{ki}, β_{kii} and β_{kij} are constant regression coefficients; x is the coded independent variable. The mathematical models were evaluated for each response by means of multiple linear regression analysis. Modeling was started with a quadratic model including linear, squared and interaction terms.

The design includes 17 experiments. This software optimizes the process of osmotic dehydration of potato in determining the best combination between variables. The levels of the different variables of the process of osmotic dehydration of the potato slices in a sucrose solution (time, concentration, temperature) are shown in (Table 1).

Table 1: The Levels of the different Variables in Coded and un-coded form of the Process of Osmotic Dehydration of Potato Slices in a Sucrose Solution

Independent Variables	Range and levels		
	-1	0	+1
A : Temperature (°C)	20	40	60
B : Processing time (min)	80	150	300
C :Sugar concentration (%w/w)	40	50	60

Frying Potato

Frying potato chips or potato slices was carried out in a deep domestic stove using a hot plate that stabilizes the temperature. For this test two samples were used:

- Natural chips without any pretreatment
- Chips previously dehydrated at 40 ° C, 60 ° B for a period of 300 minutes.

Potato slices are deposited on a torchant and covered with paper towels and then baked for two minutes in soybean oil and corn to a temperature of 170 ° C. The chips are cooked when they become golden and when silence settles in the frying oil (Anonymous, 2011).

RESULTS AND DISCUSSIONS

The effect of process variables like temperature, processing time, sugar concentration on osmotic dehydration of potato was investigated using response surface methodology according to central composite designCCD. Experiments were performed according to the CCD experimental design given in Table 2 in order to search for the optimum combination of parameters for the osmotic dehydration of potato. Table 2shows that in order to obtain high levels of water loss, osmotic dehydration should be conducted at elevated temperatures and long times, but the increase in solid gain is inevitable in this case.

Table 2: Experimental Conditions and Observed Responses Values Obtained by RSM

RunN°	A	B	C	WR%	WL%	SG%
1	0	0	0	57.2	57.55	2.06
2	0	0	0	57.2	52.41	2.06
3	+1	-1	0	50	59	10.31
4	-1	0	+1	45.9	47.25	3.37
5	-1	+1	0	52.2	56.3	0.35
6	0	-1	+1	50.9	52.41	2.63
7	-1	0	-1	43.5	45	0.86
8	-1	-1	0	32.7	32.08	0.43
9	+1	+1	0	58.6	71.87	14.06
10	0	0	0	57.2	57.55	2.06
11	0	-1	-1	42	48.3	7.28
12	0	+1	+1	66.8	69.34	3.56
13	+1	0	-1	48	62.08	14.11
14	0	+1	-1	51.8	60.92	9.13
15	0	0	0	57.2	57.55	2.06
16	+1	0	+1	55.4	63.48	10.18
17	0	0	0	57.2	57.55	2.06

Fitting Models

The experiments were performed using a central composite design presented in Table 2. The values 12.44, 9.17 and 3.78 allows to conclude that the lack of fit is not significant (table 3), it means that the gap between the theoretical model and experimental model is negligible. The test F- Fischer with a low probability value Pmodèle> F = 0.0001) showed a high significance of the regression model. The quality of the fit of the model is verified by the regression coefficient (R^2). The regression coefficients R^2 respectively obtained for the weight reduction, water loss and solid gain are 0.9631, 0.9805, and 0.9681. This implies that more than 98% of the experimental data are compatible with the predicted data of the model and that less than 2% of total variations are not explained by the model. The value of R2 is between 0

and 1, and a value greater than 0.75 confirms the reliability of the model. The adjusted R2 value corrects the value of R2 according to the sample size and the number of terms in the model. The adjusted R2 values are 0.9157, 0.9554, and 0.9271 respectively for weight reduction, water loss, solid gain;these values are high enough to justify the great significance of the model. If there are many terms in the model and the sample size is not large, the adjusted R2 can be substantially lower than the R2. Here, in this case, the adjusted R2 value is less than R2. Adequate accuracy is the signal to noise ratio. A ratio greater than 4 is desirable. In this work, the report is found to be > 20witch indicates an adequate signal.

The mathematical expression of the relationship between the answer (WR, WL, SG) and variables of osmotic dehydration (A, B, C) is indicated in equations (I, II, III).

Where WL, WR, and SG are respectively: water loss (%), weight reduction (%), and the solid gain (%).

WR = + 57.20 + 4.71 * A + 6.73 * B + 4.21 * C – 2.72 * A * B + 1.25 * A * C+ 1.52 * B * C – 6.75 * A^2 – 2.08 * B^2 – 2.25 * C^2 …… (I)

WL = + 57.55 + 9.48 * A + 8.33 * B + 2.02 * C – 2.84 * A * B – 0.21 * A * C + 1.08 * B * C – 3.01 * A^2 + 0.28 * B^2 – 0.084 * C^2… (II)

SG = + 2.06 + 5.46 * A + 0.81 * B – 1.46 * C + 0.96 * A * B – 1.61 * A * C-0.23 * B * C + 2.85 * A^2 + 1.37 * B^2 + 2.22 * C^2……… (III)

A, B, C, are respectively the coded values of the following variables tested: temperature (°C), time (min) concentration of sucrose (% w / w). The results of multiple linear regressions performed for the model of second degree response surface are given in Table 3. The significance of each coefficient is determined by the -Student test and P values listed on table3. More amplitude F is high and the value of P is low over the corresponding coefficient is significant. The values of " Prob> F " below 0.0500 indicates that factors in the model are significant. Values greater than 0.10 indicate that factors in the model are not significant.

Table3: Analysis of Variance (ANOVA) for Response Surface Quadratic Model for the Osmotic Dehydration of Potato Slices

Source	Weight Reduction			Water Loss			Solid gain		
	Coefficient	Sum of Squares	p-value	Coefficient	Sum of Squares	p-value	Coefficient	Sum of Squares	p-value
Model	57.20	108.36	0.0003	57.55	153.51	< 0.0001	2.06	38.23	0.0002
A	4.71	177.66	0.0007	9.48	718.21	< 0.0001	5.46	238.17	< 0.0001
B	6.73	361.81	<0.0001	8.33	555.11	< 0.0001	0.81	5.20	0.1162
C	4.21	141.96	0.0013	2.02	32.72	0.0234	-1.46	16.94	0.0144
AB	-2.72	29.70	0.0503	-2.84	32.21	0.0242	0.96	3.67	0.1761
AC	1.25	6.25	0.3149	-0.21	0.18	0.8363	-1.61	10.37	0.0392
BC	1.52	9.30	0.2281	1.08	4.64	0.3129	-0.23	0.21	0.7284
A^2	-6.75	191.84	0.0005	-3.01	38.24	0.0168	2.85	34.29	0.0025
B^2	-2.08	18.13	0.1078	0.28	0.32	0.7832	1.37	7.95	0.0623
C^2	-2.25	21.32	0.0857	-0.084	0.030	0.9333	2.22	20.68	0.0091
Residuel		5.33			3.93			1.62	
Lack of fit		12.44			9.17			3.78	
R^2		0.9631			0.9805			0.9681	
Adj-R^2		0.9157			0.9554			0.9271	
Préd-R^2		0.9362			0.9378			0.9197	

The sign and magnitude of the coefficients specify the effects of the variables on the response. The negative sign of the coefficient means that the response decreases as the variable increases, while a positive sign indicates an increase in the response. Montgomery (2004) reported that for the positive interaction on the level of one of the interactive variables may increase while the other decreases in order to achieve a constant value of the response.

Quadratic effects indicate that in a first step, the value assigned to the response variable increases significantly (up to a maximum point) as the variable increases. In a second time, after a maximum response point, the effect of increasing the variable becomes negative. To visualize the combined effects of the variables on the responses, response surfaces were performed using two independent variables while keeping the third as a central value.

Weight Reduction

The maximum weight reduction obtained for osmotic dehydration of potato slices carried out at 40 ° C, 60 ° Brix, for 300 min is 66.8 %, while the minimum is 32.7 % obtained for osmotic dehydration at 20 ° C, 40 ° Brix for 80 minutes (Table 2).

Estimation coefficients indicate the positive effect on the WR of the osmotic dehydration period followed by temperature and the sucrose concentration of the osmotic solution (table 3); therefore the increase of these factors causes anincrease in the WR. These results are confirmed in figures 1, 2, 3.

The interactions AC, BC had a positive effect on WR unlike the interaction AB which has a negative effect. All quadratic terms A^2, B^2, C^2present a negative effect on the WR of the potato slices.

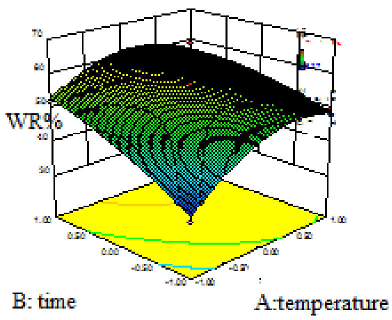

Figure 1: Response Surface of the Effect of Time and Temperature on the Weight Reduction of Potato Slices

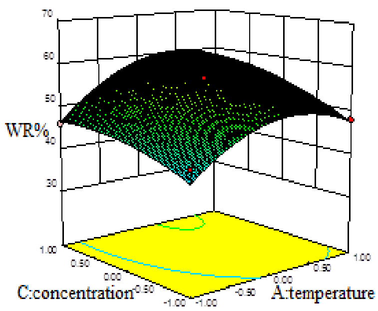

Figure 2: Response Surface of the Effect of Temperature and Sucrose Concentration on the Weight Reduction of Potato Slices

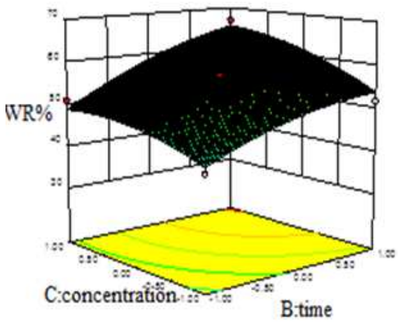

Figure 3: Response surface of the effect of time and the sucrose concentration on the weight reduction of potato slices

Water Loss

The maximum WL is 71.87 % obtained for osmotic dehydration behavior at 60°C, 40° Brix, to an immersion time of 300 min while the minimum of 32.08 % is obtained for an osmotic dehydration performed under the following conditions: 20°C, 40 ° Brix, and 80 min (Table 2).

The estimation coefficients show a positive effect on WL of linear model terms A, B, C(Table 3). This means that WL potato slices increases with increasing of temperature followed by the duration of osmotic dehydration and the sucrose concentration of the osmotic solution. In interactive terms, only the interaction BC has a positive effect on the water loss. Further quadratic of A^2 and C^2 have negative effect on the WL contrary to the quadratic of B^2 osmotic dehydration process which has a positive effect (Figures 4, 5, 6).

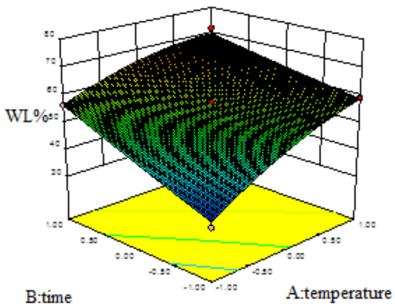

Figure 4: Response Surface of the Effect of Time and Temperature on the Water Loss of Potato Slices

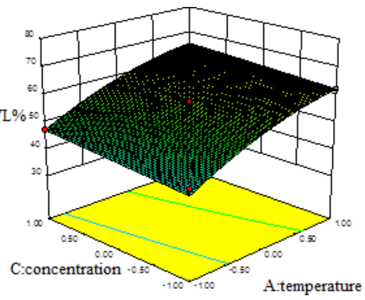

Figure 5: Response Surface of the Effect of Temperature and the Sucrose Concentration on the Water Loss of Potato Slices

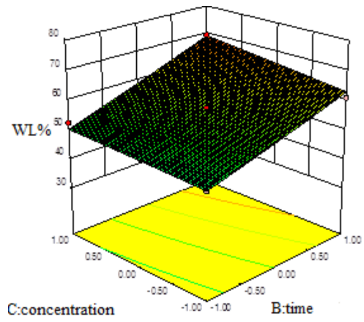

Figure 6: Response Surface of the effect of Time and the Sucrose Concentration on the Water Loss of Potato Slices

Solid Gain

Osmotic dehydration behavior at 60°C, 20°Brix and a process time of 150 min gives a maximum SG of 14.11 %, while the minimum is 0.35 % obtained under the following conditions 20°C, 40°Brix, an immersion time of 150 min (Table 2).

The estimation coefficients indicate the positive influence on the SG of A and B and the negative influence of C(Table 3).

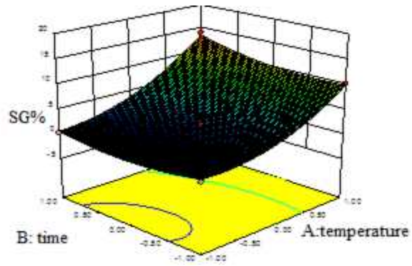

Figure 7: Response Surface of the Effect of Time and Temperature on the Solid Gain of Potato Slices

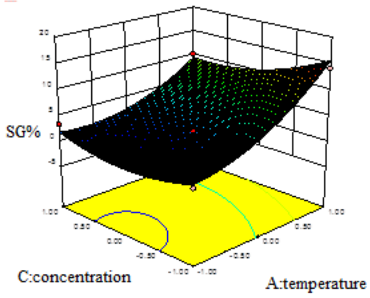

Figure 8: Response Surface of the Effect of the Temperature and the Sucrose Concentration on the Solid Gain of Potato Slices

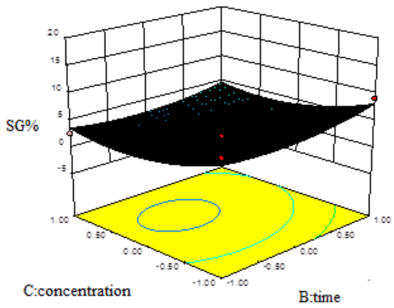

Figure 9: Response Surface of the Effect of Time and the Sucrose Concentration on the Solid Gain of Potato Slices

These results show that the SG increases with increasing temperature of the osmotic solution and the duration of the process and decreases with increase in sucrose concentration of the osmotic solution; this is clearly illustrated in figures7, 8, 9. In the interactive terms, only the AB interaction has a positive effect unlike interactions AC, BC which have a negative effect. Furthermore all quadratic terms A^2, B^2, C^2 have a positive effect on the SG.

Frying Potato

Table 4: Frying Time of Chips

Chips / Samples	Frying Time in Seconds	
	Natural Chips	**Dehydrated Chips**
1	70	44
2	78	43
3	73	46
4	73	42
Average	**73,5**	**43,75**

The frying time of dehydrated chips is shorter compared with natural chips (Table 4). This means that heat transfers are faster for dehydrated products, which can be explained by:

- A larger amount of water contained in the raw chips that tends to slow the progression of the heat front ;
- An amount of water vapor that is released and which significantly disturb the heat transfer at the interface of oil bath / product. This disruption lasts longer for raw chips;
- Sucrose added to the composition of the dried chips absorbs heat and facilitates the transmission chips. These findings are confirmed by those obtained by CT Mbaye, Ndour C. (2004) in the study of the combination process osmotic dehydration - frying for the valuation of mango.

Figure 10: Potato Chips

CONCLUSIONS

Response Surface Methodology was used to determine theoptimum operating conditions that yield maximum water loss and weight reduction and minimum solid gain in osmotic dehydration of potatoes. Analysis of variance has shown that the effects of all the process variables including temperature, time, sucrose and concentrations were statistically significant. Second order polynomial models were obtained for predicting water loss, solid gain and weight reduction.

The optimal conditions for maximum water loss, weightreduction and minimal solid gain correspond to temperature of 60°C, processing time of 300 min and sugar concentration of 60% in order to obtain water loss of 69.34% (g/100 g fresh sample), solid gain of 3.56% (g/100 g fresh sample) and weight reduction of 66.8% (g/100 g fresh sample).

Use of potato slices dehydrated prior to the preparation of chips has reduced the frying time 40.47 % for sweet potato chips.

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